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DEVELOPMENT OF AN ARTIFICIAL VISCOSITY FUNCTION

September 1977

Final Report

Approved for public release; distribution unlimited

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

AFWL-TR-77-53

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico , under Job Order 88091816. Mr Charles E Needham (DYM) was the Laboratory Project Officer-in-Charge.

This technical report has been reviewed and is approved for publication.

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The hydrodynamics code HULL used by the Air Force Weapons Laboratory (AFWL) uses the Von Neumann-Richtmeyer method to maintain stability in the numerical computation of a propagating shock. This method adds a pseudoviscous term to the pressure in a compression region. Care is needed in the application of this method, however. Too little artificial viscosity will not maintain stability. Too much will "smear" the shock over many zones, making the shock practically continuous. The AFWL has developed a relation which expresses the linear

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20. ABSTRACT (Cont'd)

viscosity coefficient as a function of maximum density. The effect of this variable viscosity coefficient is to maintain stability while limiting the smear to 10 zones for overpressure levels of 2 psi to 1200 psi in air.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

SECTION I

INTRODUCTION

The Air Force Weapons Laboratory (AFWL) has been tasked to calculate the blast loading on a shelter due to a burst. For this problem a shock front will be needed which is stable as it propagates through the air, yet is sharply defined (spread over as few zones as possible). To provide the stability, we have used the well-known technique of adding a pseudo-viscous pressure, or artificial viscosity, into the hydrodynamic equations (ref. 1). Stronger shocks require larger viscosity coefficients than weaker shocks to maintain stability, but using the larger coefficients in the weaker shocks smears the shock front over many zones. This is unacceptable for the shelter calculations since the peak overpressure on the shelter as a function of time is required. As the calculations will be made for many pressure levels, the AFWL has developed a formula for the linear viscosity coefficient as a function of pressure ratio.

A preliminary problem set was devised in order to generate and evaluate the incident waveform over a wide range of pressures. In order to generate the incident square wave, the left boundary conditions for the HULL (ref. 2) 2-D code were modified to include a subroutine which used Rankine-Hugoniot relations to specify the density, horizontal particle velocity and internal energy of air for any incident pressure level. For the pressure ranges in this report, γ (the ratio of specific heats) was a constant = 1.4.

The ambient values used were:

pressure	P_o	1.00156E6	dynes/cm^2 = 14.53 psi
density	ρ_o	1.22499E-3	gm/cm^3
sound speed	C_o	3.38327E4	cm/sec
energy	I_o	2.044E9	ergs/gm

The parameters used to specify the incident waveform at various test pressures were:

P (psi)	RHO (gm/cm³)	I (ergs/gm)	U (cm/sec)
2	1.343447E-3	2.1208678E9	3.1466528E3
20	2.2316484E-3	2.6666835E9	2.2533251E4
200	5.2854412E-3	6.9958019E9	9.2991486E4

where P is the incident overpressure, RHO, I, and U are the density, specific internal energy, and velocity of the material behind the shock front, respectively. The variable P is the desired incident overpressure and is specified in subroutine LBOUND. Variables RHO, I, and U are input variables for a package of air. These input variables are determined from Rankine-Hugoniot relations where P_{so} is the incident overpressure, cs is the ambient sound speed, and $\gamma = 1.4$:

$$\rho = \rho_o \left[\frac{7 + 6\, P_{so}/P_o}{7 + P_{so}/P_o} \right]$$

$$U = \frac{5\, P_{so}}{7\, P_o} \left[\frac{cs}{(1 + 6\, P_{so}/7\, P_o)^{1/2}} \right]$$

and

$$I = \frac{P_o + P_{so}}{.4\rho}$$

A two-dimensional rectangular universe was generated with x = 200 cm and y = 10 cm, forming a matrix of 100 x 6 zones. The timeframe of interest was 10 μs to 5 ms. In this way both the incident and reflected waveforms could be observed, giving information concerning the stability and shape of the waveform at different pressures.

SECTION II

TWO PSI CALCULATIONS

DEFAULT WAVEFORM

For the first problem (19.8010) the incident pressure was the default value, 2 psi. This problem was run to check the left boundary conditions and to evaluate the default waveform (no artifical viscosity). The HULL code adjusts its time step using the Courant condition which says simply that no signal may propagate a distance greater than the smallest zone size in one time step. For further control, the user may set a variable STABF (stability factor) which multiplies the Courant-determined time step to calculate the final time step used by the code. For the default waveform, the stability factor was 0.5. The left boundary conditions (where the waveform is generated) were seen to be quite stable. The incident waveform oscillated somewhat at early times due to the finite differencing, but when the wavefront hit the wall (at 2.5 msec), much of the oscillation was smoothed out and the pressure overshoot was about 0.7% (fig. 1). The leading edge was smeared over about ten zones. The reflected wave (4.2 psi overpressure) was smeared over approximately 15 zones, with an overshoot of about 0.9% at 4.8 msec (fig. 2).

THE EFFECT OF THE STABILITY FACTOR

A second problem (19.8011) was run with the same input conditions as the default waveform except that the stability factor was decreased by an order of magnitude to 0.05, also with no artifical viscosity. The wave propagated at about the same velocity as the default waveform, but required over six times the number of cycles in order to reach the wall. The early oscillations did not smooth out as the waveform moved down the tube. Instead, the waveform became increasingly unstable. The pressure overshoot for the incident wave at 2.5 msec was about 2.5% (fig. 3) and by 4.8 msec the reflected wave overshoot was about 3.8% (fig. 4). The incident wave (2.5 msec) was smeared over about 12 zones. We conclude that the default stability factor (0.5) is more suitable for these problems, giving a better waveform at reduced cost (because fewer cycles are required for propagation).

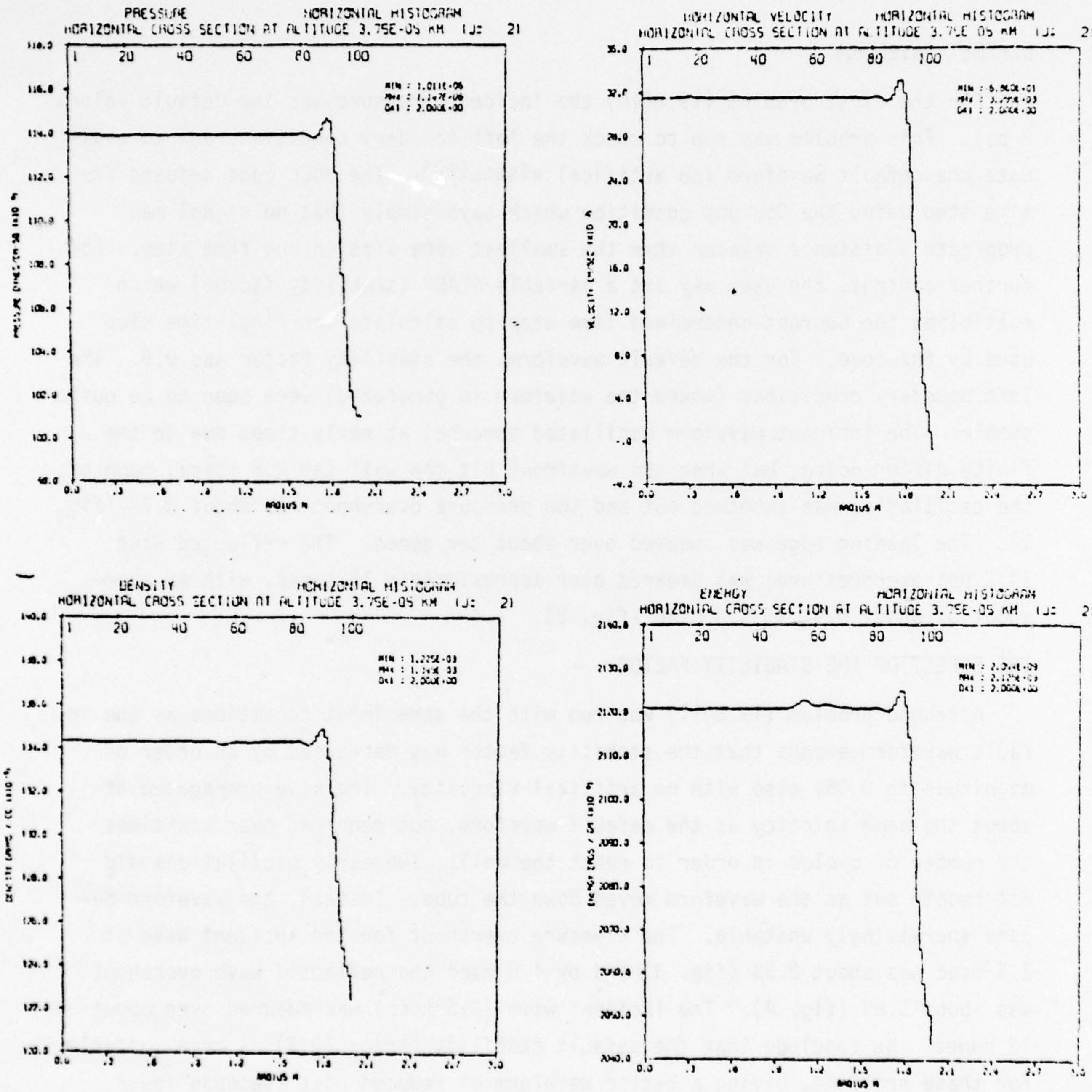

Figure 1. AFWL - 2 psi Square Wave on Wall - No Viscosity
Time - 2.5 msec, Problem 19.8010.

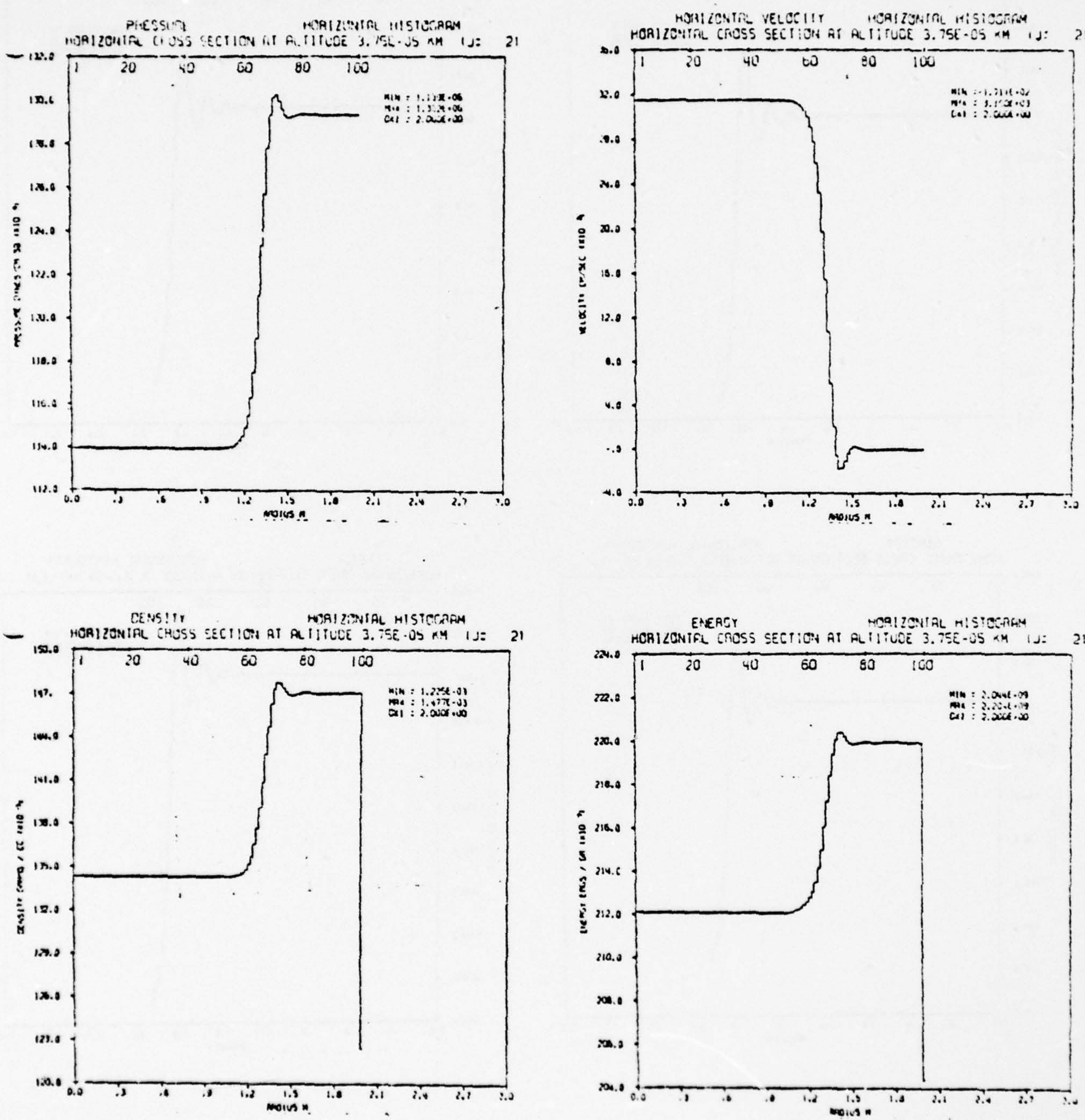

Figure 2. AFWL - 2 psi Square Wave on Wall - No Visibility
Time - 4.8 msec, Problem 19.8010.

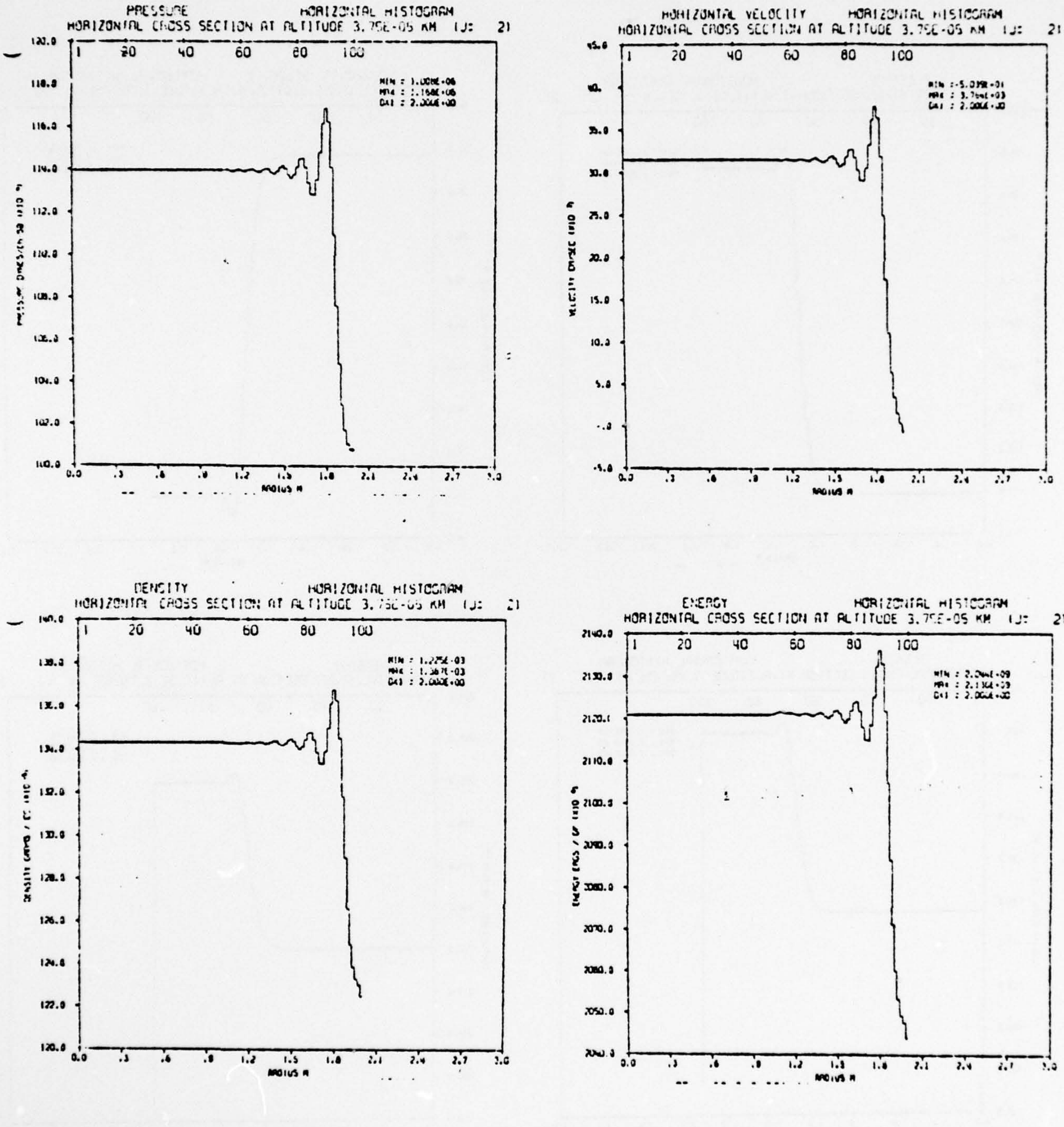

Figure 3. AFWL - 2 psi Square Wave on Wall - STABF = 0.05
Time - 2.5 msec, Problem 19.801i.

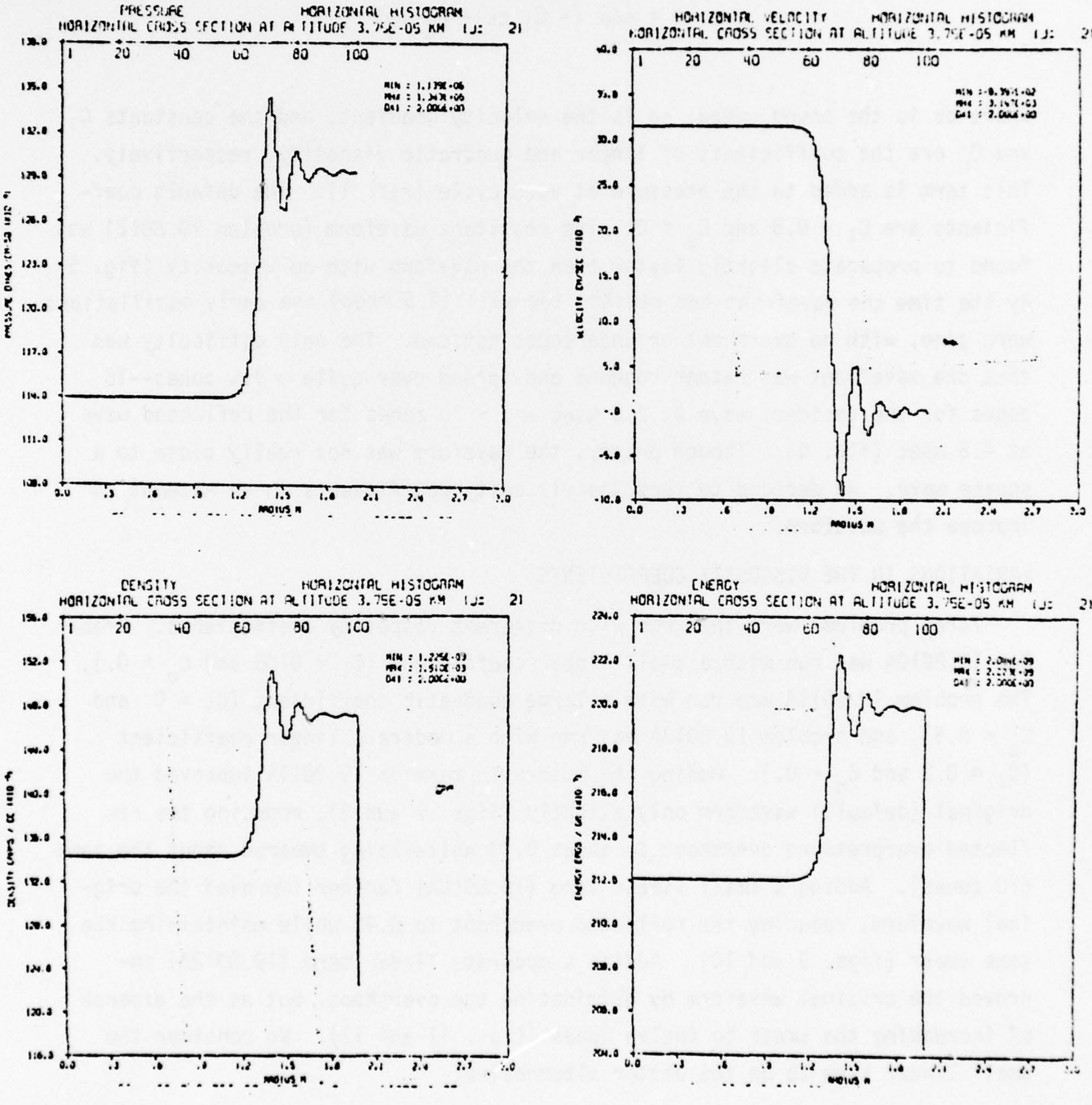

Figure 4. AFWL - 2 psi Square Wave on Wall - STABF = 0.05
Time - 4.8 msec, Problem 19.3011.

DEFAULT ARTIFICIAL VISCOSITY

The third problem (19.8012) was run with the artificial viscosity option turned on. This option provides a pseudoviscous term

$$q = \rho \Delta u \; (- C_1 \, cs + C_0 \; \Delta u)$$

where cs is the sound speed, Δu is the velocity gradient, and the constants C_1 and C_0 are the coefficients of linear and quadratic viscosity, respectively. This term is added to the pressure at each cycle (ref. 1). The default coefficients are $C_1 = 0.5$ and $C_0 = 0$. The resultant waveform (problem 19.8012) was found to propagate slightly faster than the waveform with no viscosity (fig. 5). By the time the wavefront had reached the wall (2.5 msec) the early oscillations were gone, with no overshoot or undershoot noticed. The only difficulty was that the wavefront was rather rounded and spread over quite a few zones--15 zones for the incident wave at 2.5 msec and > 30 zones for the reflected wave at 4.8 msec (fig. 6). Though pretty, the waveform was not really close to a square wave. We decided to vary the viscosity coefficients in an attempt to improve the waveform.

VARIATIONS IN THE VISCOSITY COEFFICIENTS

Three problems were then run with different viscosity coefficients. Problem 19.8010A was run with a small linear coefficient ($C_1 = 0.05$ and $C_0 = 0.$), The problem 19.8011A was run with a large quadratic coefficient ($C_1 = 0.$ and $C_0 = 0.5$), and problem 19.8012A was run with a moderate linear coefficient ($C_1 = 0.2$ and $C_0 = 0.$). Adding the quadratic term in 19.8011A improved the original (default) waveform only slightly (figs. 7 and 8), reducing the reflected overpressure overshoot to about 0.7% while being smeared about the same (10 zones). Adding a small linear term (19.8010A) further improved the original waveform, reducing the reflected overshoot to 0.4% while maintaining the same smear (figs. 9 and 10). Adding a moderate linear term (19.8012A) improved the original waveform by eliminating the overshoot, but at the expense of increasing the smear to twelve zones (figs. 11 and 12). We consider the small linear term to be the better alternative.

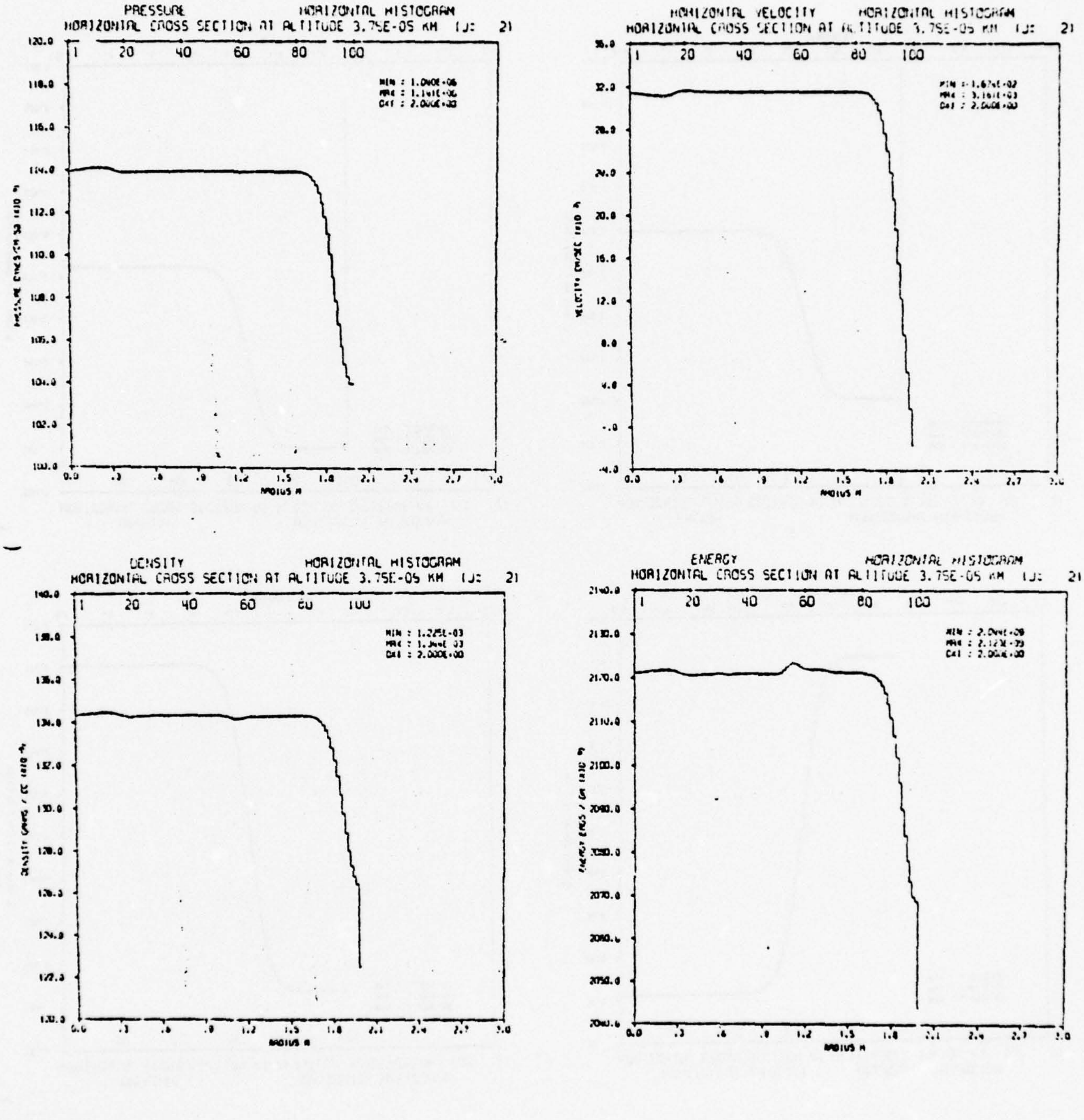

Figure 5. AFWL - 2 psi Square Wave on Wall - Default Viscosity
Time - 2.5 msec, Problem 19.8012.

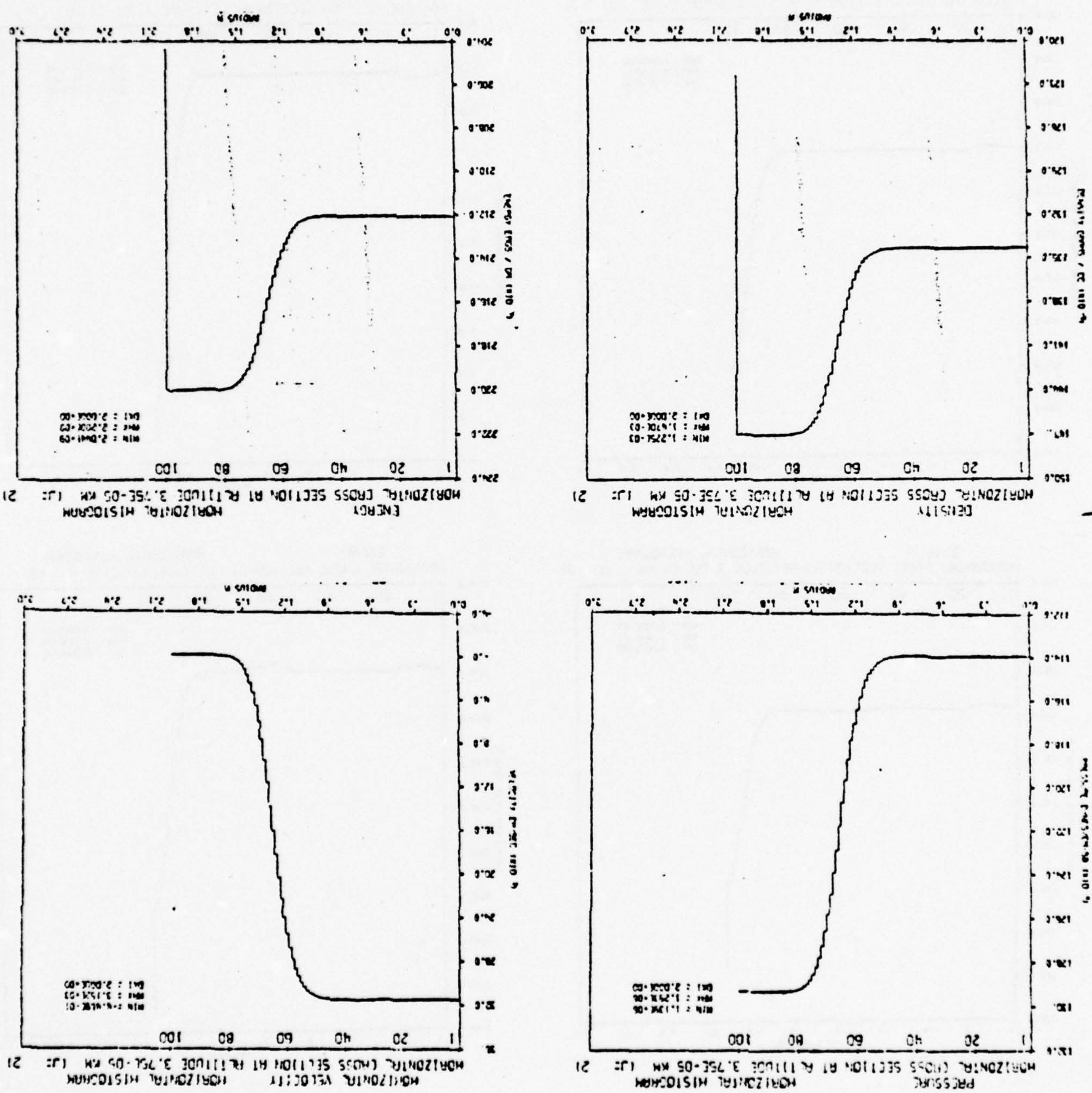

Figure 6. AFWL - 2 psi Square Wave on Wall - Default Viscosity
Time - 4.8 msec, Problem 19.8012.

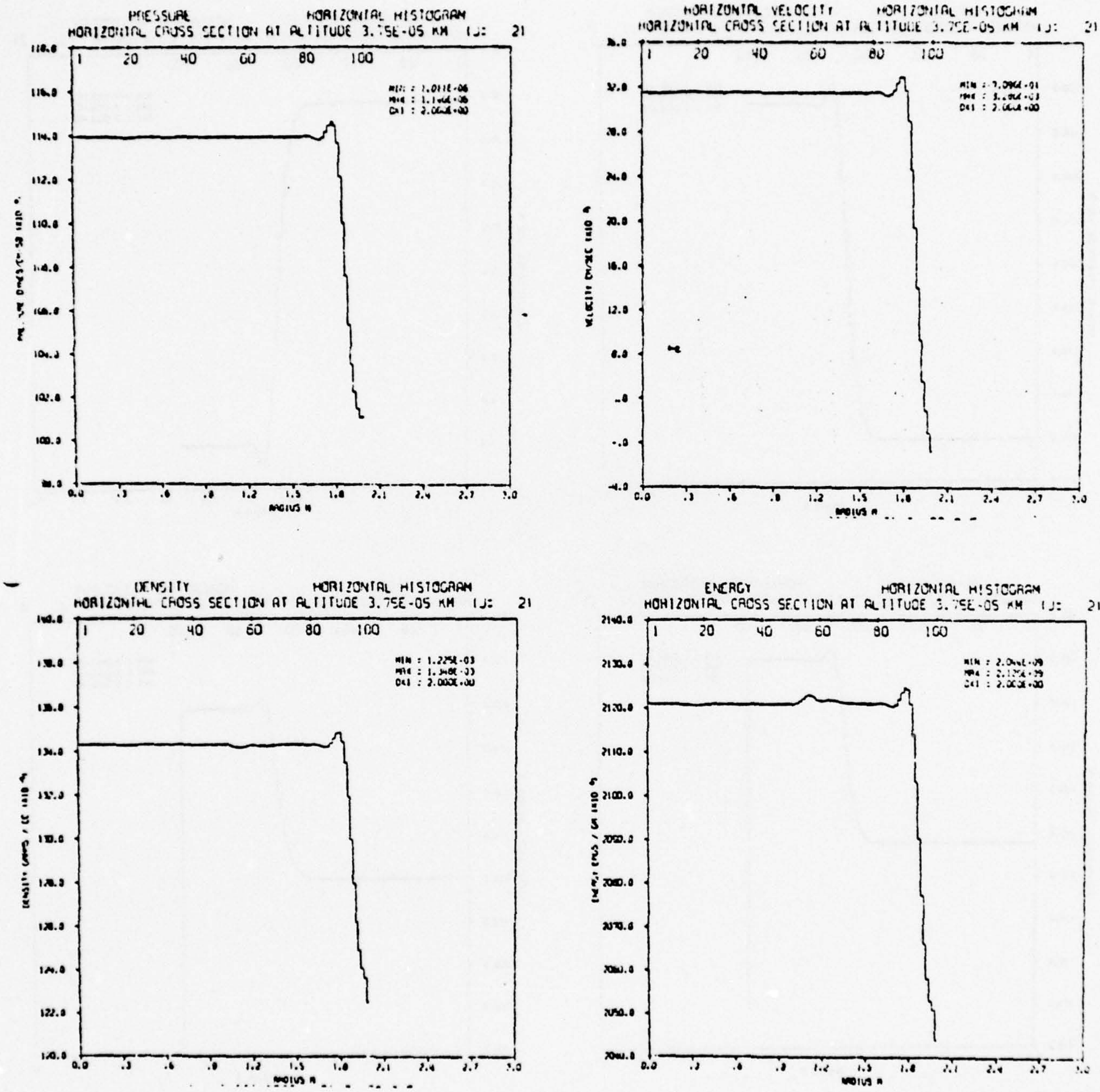

Figure 7. AFWL - 2 psi Square Wave on Wall - Large Quadratic Viscosity
Time - 2.5 msec, Problem 19.8011A.

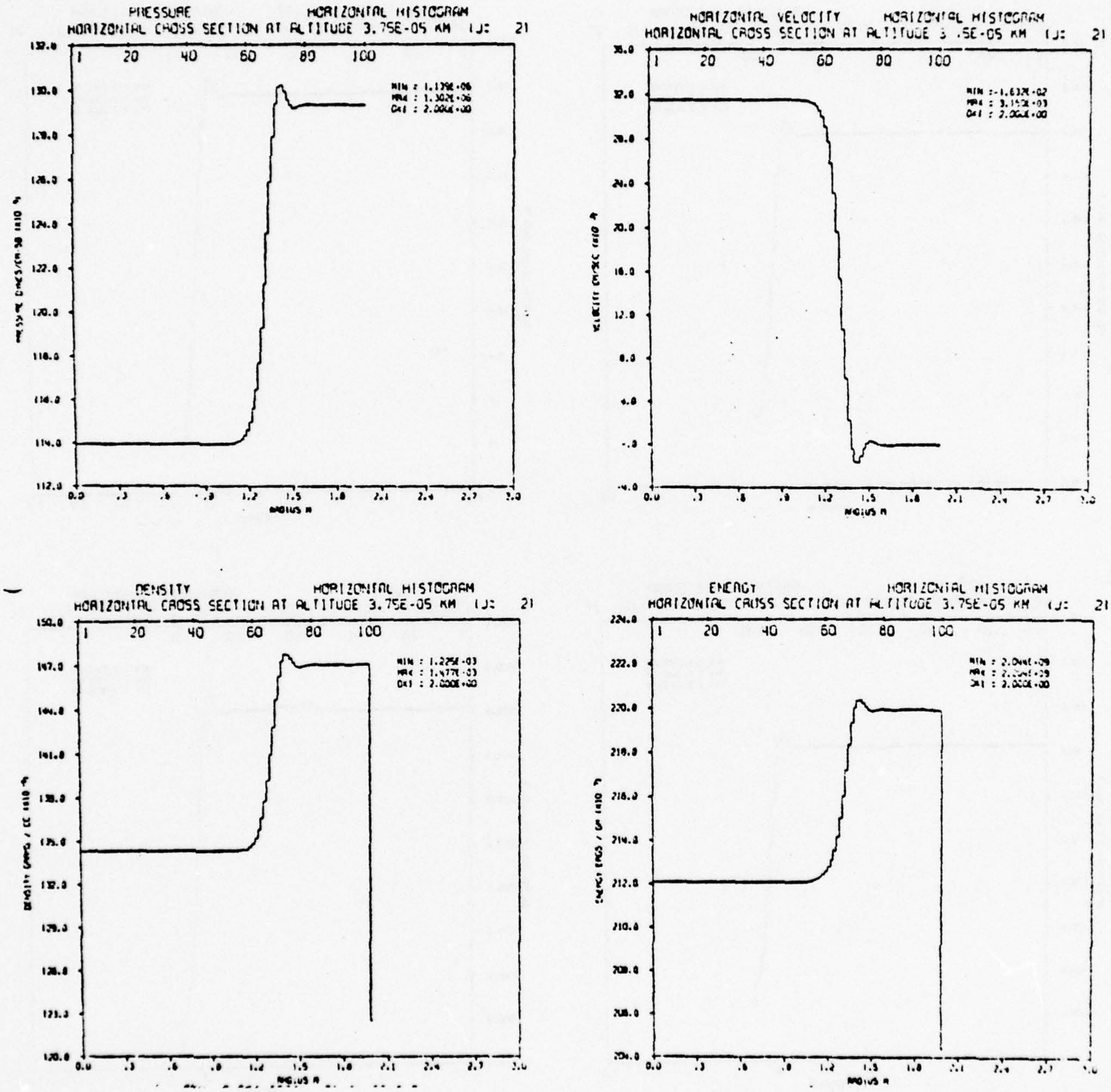

Figure 8. AFWL - 2 psi Square Wave on Wall - Large Quadratic Viscosity
Time - 4.8 msec, Problem 19.8011A.

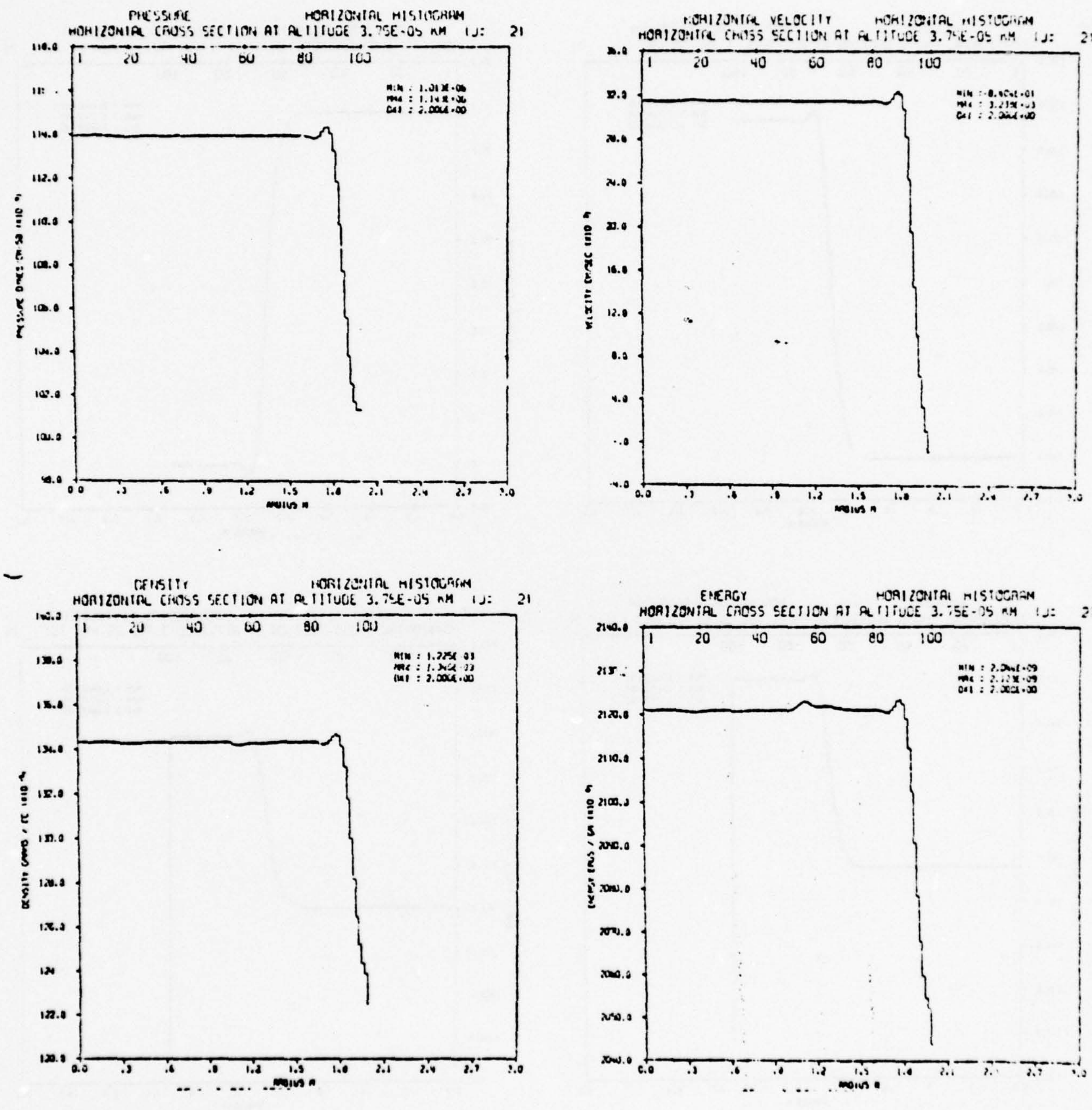

Figure 9. AFWL - 2 psi Square Wave on Wall - Small Linear Viscosity
Time - 2.5 msec, Problem 19.8010A.

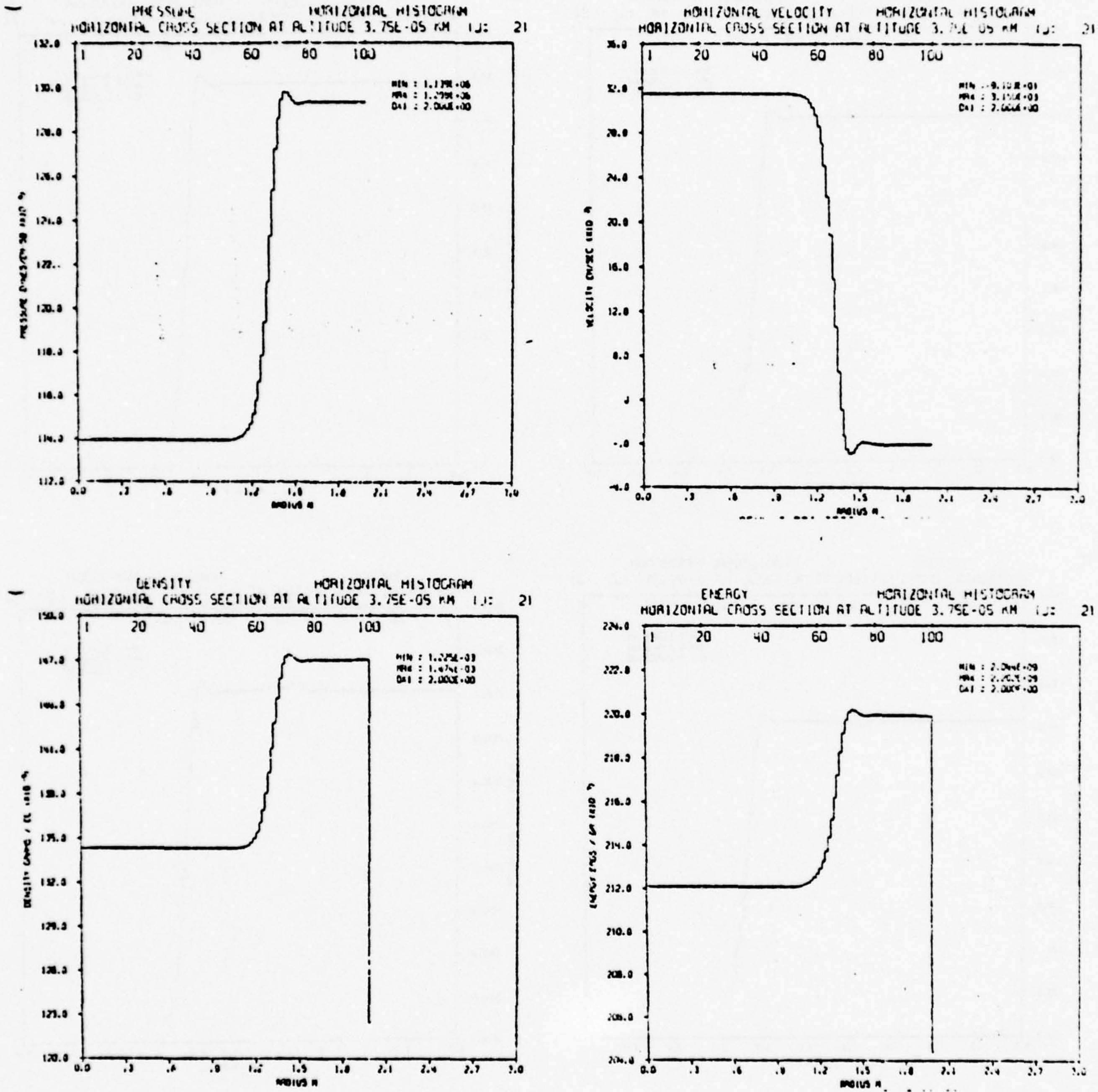

Figure 10. AFWL - 2 psi Square Wave on Wall - Small Linear Viscosity
Time - 4.8 msec, Problem 19.8010A.

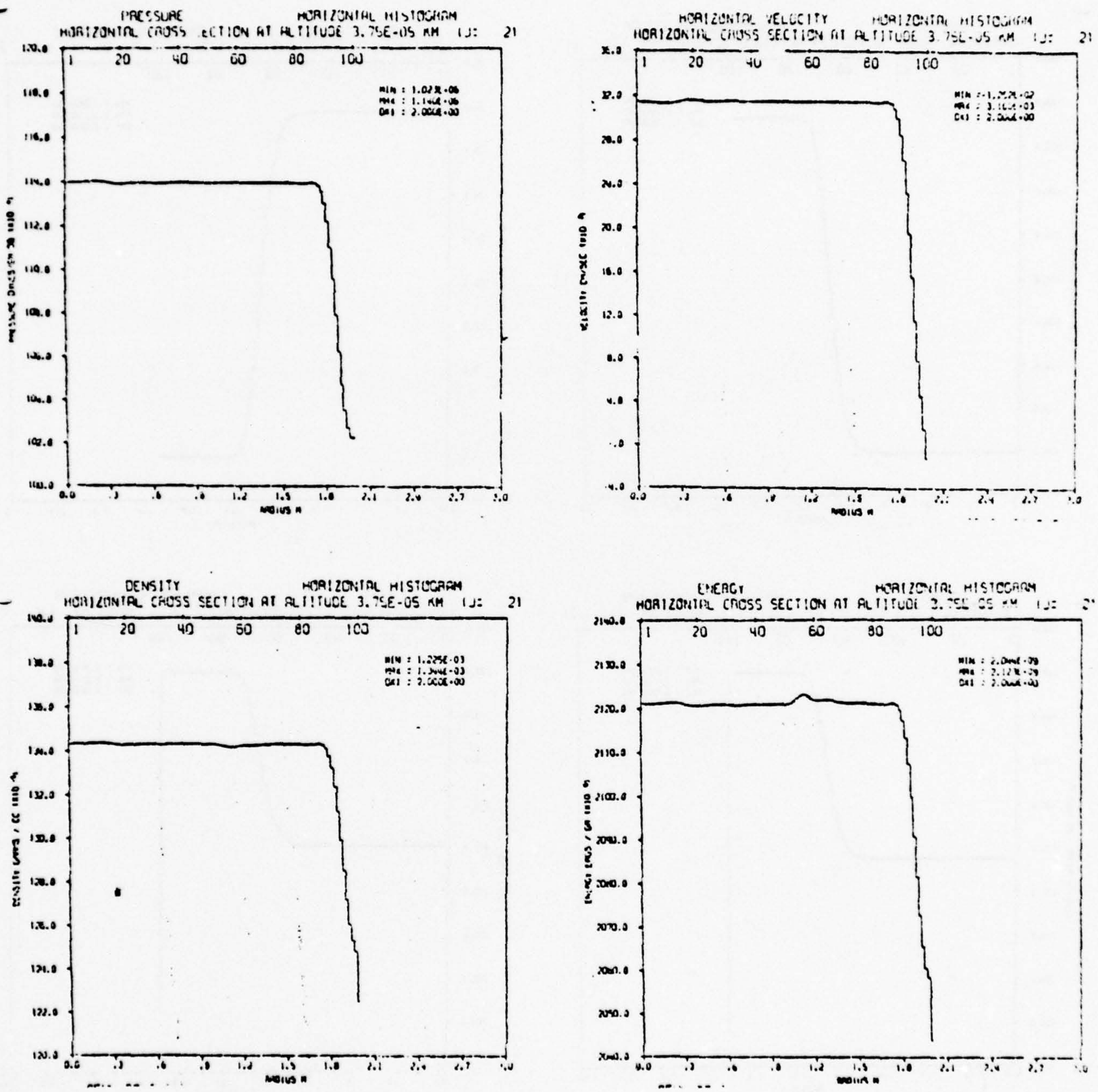

Figure 11. AFWL - 2 psi Square Wave on Wall - Moderate Linear Viscosity
Time - 2.5 msec, Problem 19.8012A.

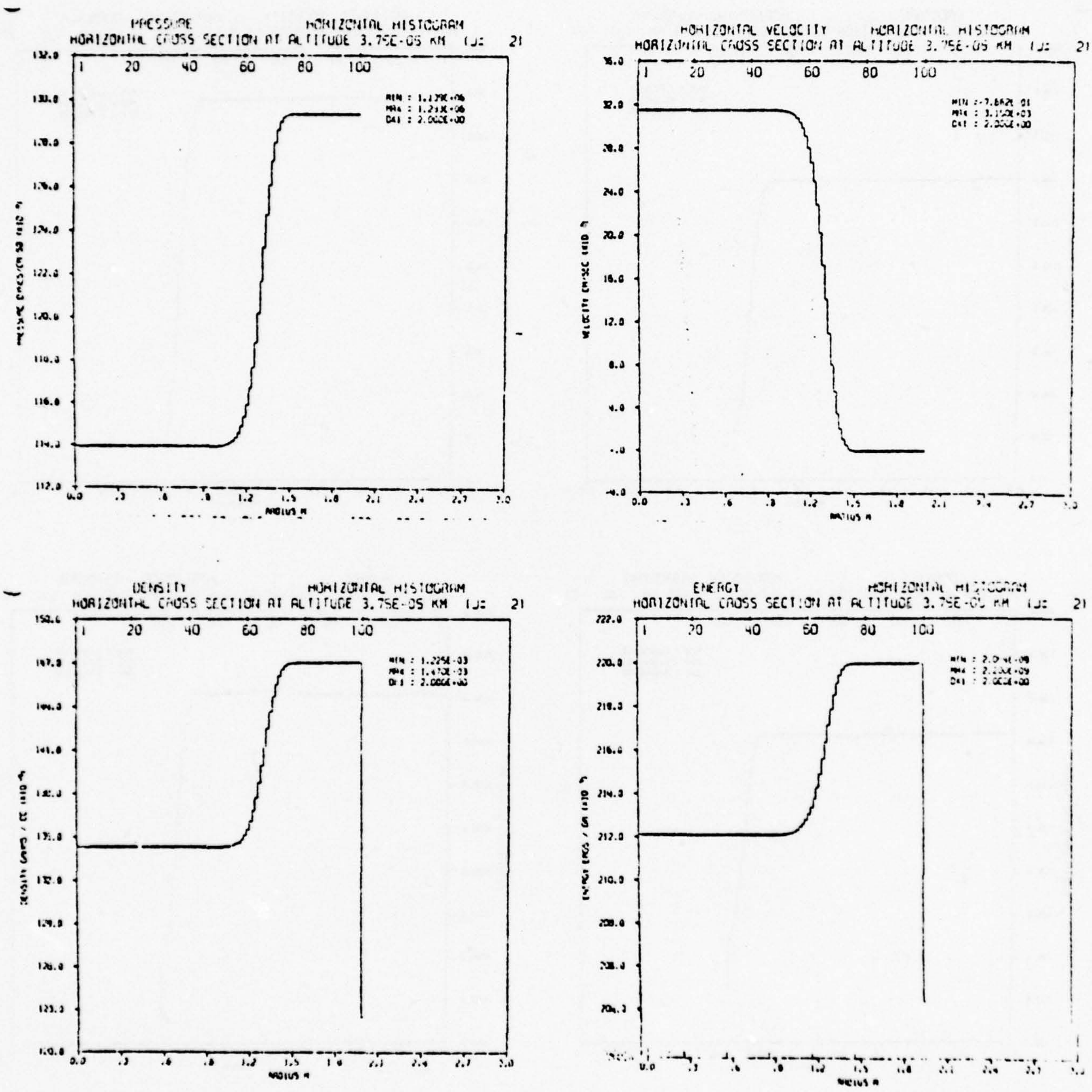

Figure 12. AFWL - 2 psi Square Wave on Wall - Moderate Linear Viscosity Time - 4.8 msec, Problem 19.8012A.

AN ARTIFICIAL VISCOSITY FUNCTION

An artifical viscosity function was developed to provide an appropriate artificial viscosity coefficient for any incident overpressure between 2 psi and about 1200 psi. This formulation is an empirical fit applied to SAP (ref. 3, a 1-D Lagrangian code) to develop the 1-KT Standard (ref. 4). A slowly-varying function of pressure was needed which approaches an upper limit as pressure increases. Density as a function of pressure satisfies these criteria. The linear coefficient of viscosity was formulated to be

$$C_1 = \sqrt{(0.1)\ Rhm} + 0.015$$

where

$$Rhm = \frac{\rho_{max}}{\rho_o} - 1, \quad \rho_{max} > \rho_o$$

and ρ_{max} is the maximum density found in the grid while ρ_o is the ambient density. The quadratic coefficient is given by

$$C_o = 0$$

With this artificial viscosity function (AVF) implemented (problem 19.8012B), C_1 was approximately 0.113 (incident) and 0.156 (reflected) (figs. 13 and 14). With these coefficients, the 2 psi waveform was comparable to the best of the preceding runs, problem 19.8010A. On the incident wave the overshoot was only 0.4% and the shock was smeared over 10 zones at 2.5 ms. At 4.8 ms the overshoot was less than 0.2%, while the shock smeared 15 zones.

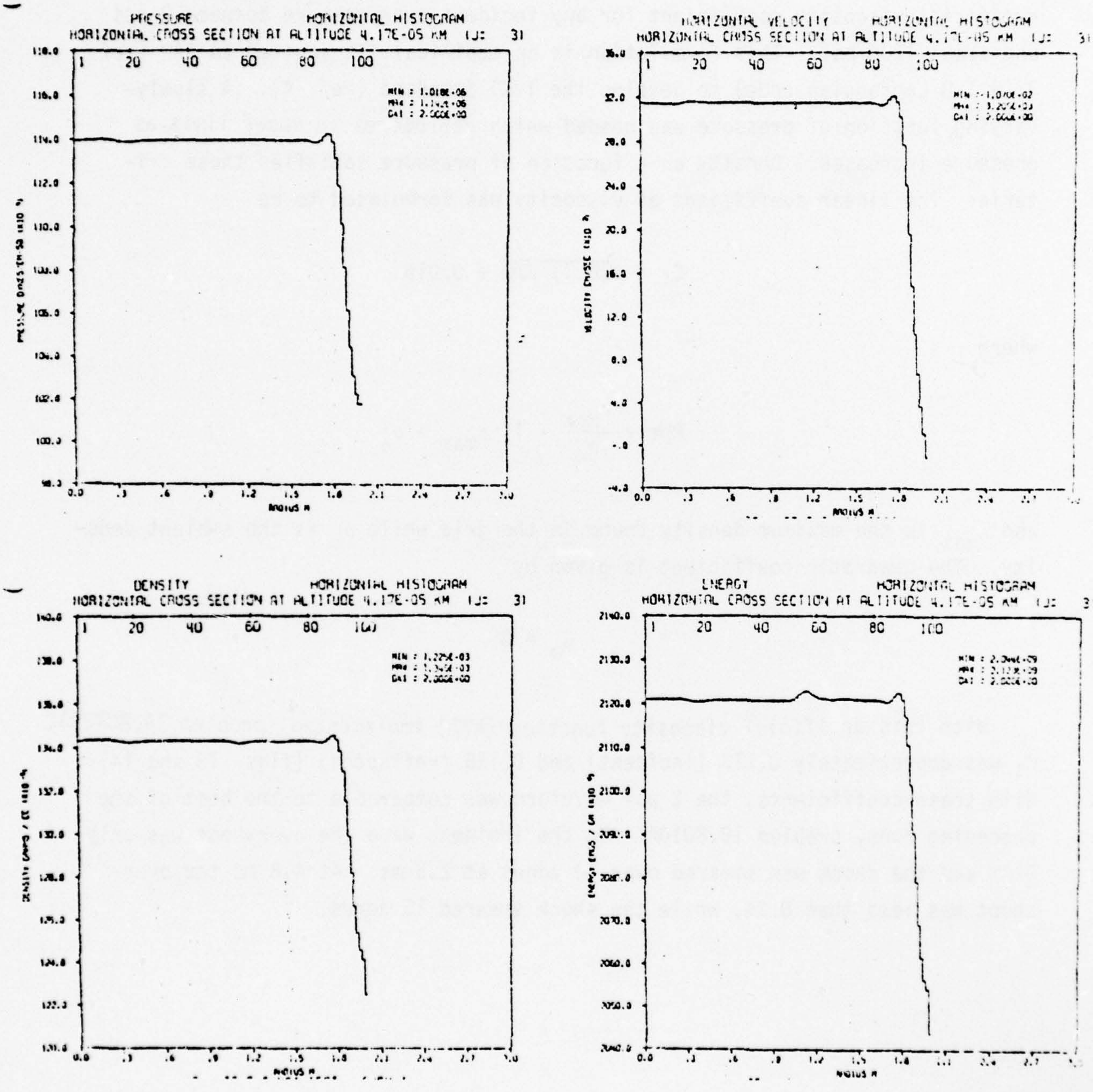

Figure 13. AFWL - 2 psi Square Wave on Wall - Viscosity Function
Time - 2.5 msec, Problem 19.8012B.

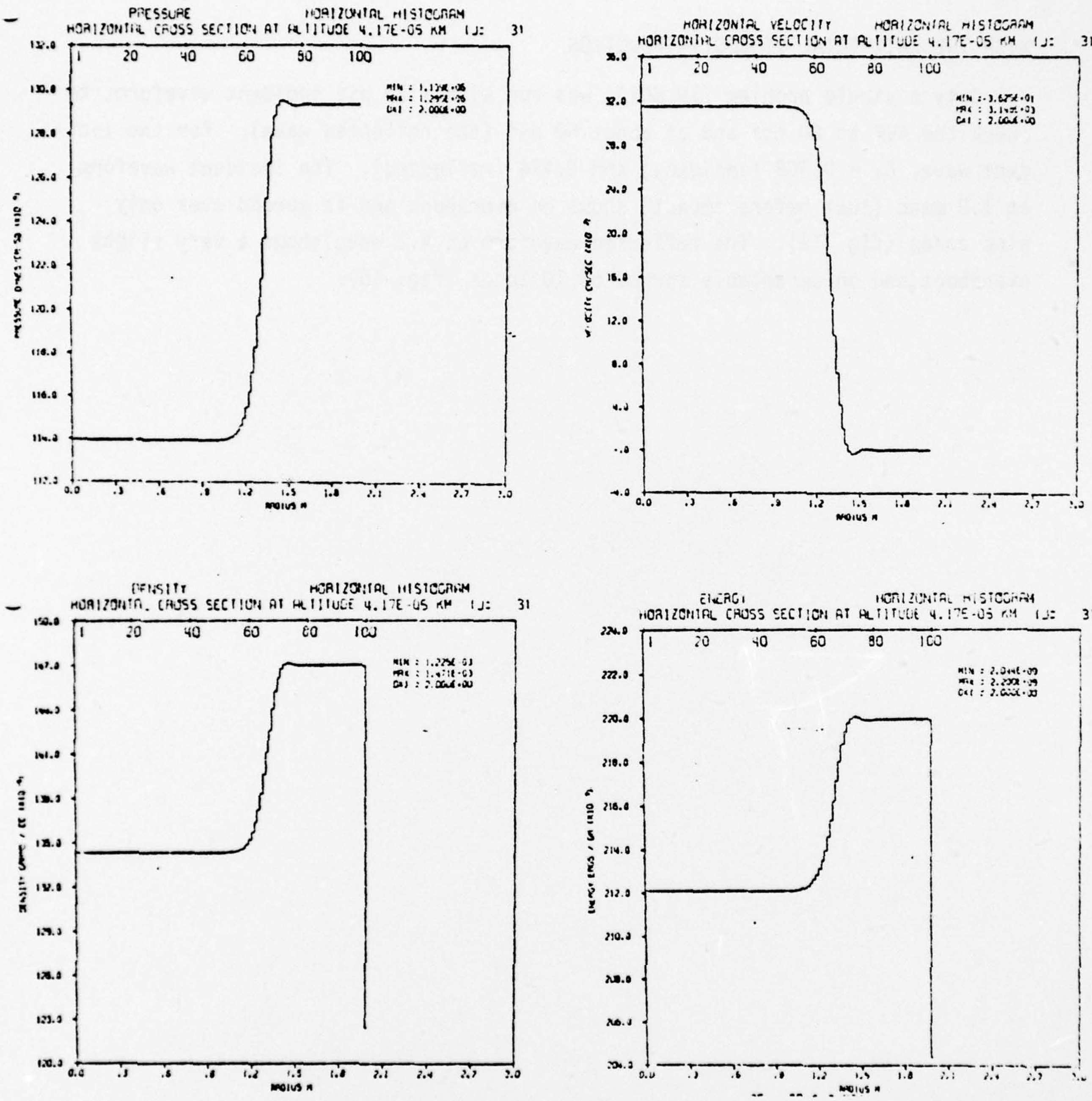

Figure 14. AFWL - 2 psi Square Wave on Wall - Viscosity Function
Time - 4.8 msec, Problem 19.8012B.

SECTION III

TWENTY PSI CALCULATION

WITH THE ARTIFICIAL VISCOSITY FUNCTION

Only a single problem (19.8013) was run with a 20 psi incident waveform, to check the AVF at 20 psi and at about 60 psi (the reflected wave). For the incident wave, C_1 = 0.302 (incident) and 0.474 (reflected). The incident waveform at 1.8 msec (just before impact) shows no overshoot and is spread over only nine zones (fig. 15). The reflected waveform at 4.2 msec shows a very slight overshoot and an acceptable spread of 10 zones (fig. 16).

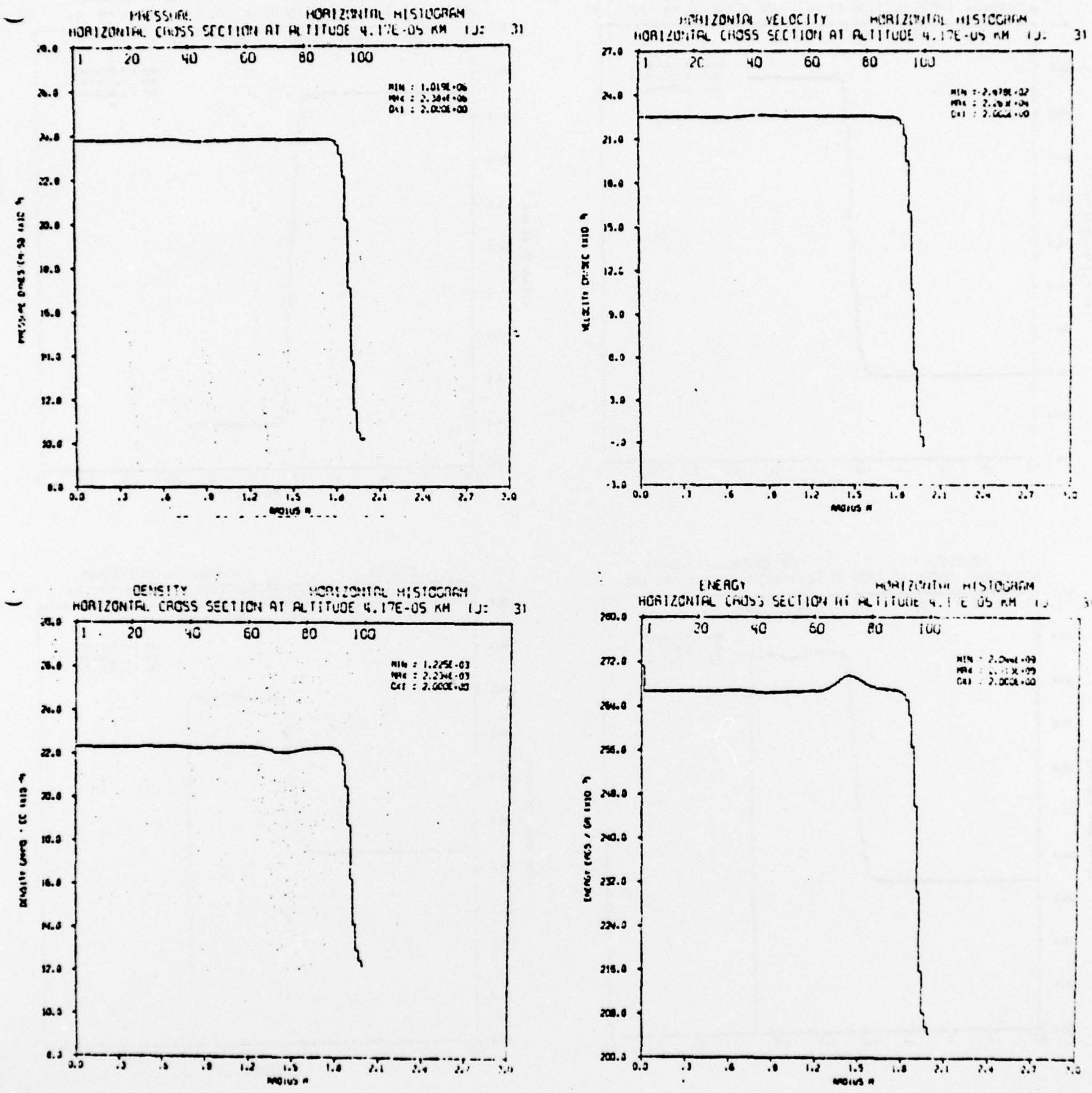

Figure 15. AFWL - 20 psi Square Wave on Wall - Viscosity Function
Time - 1.8 msec, Problem 19.8013.

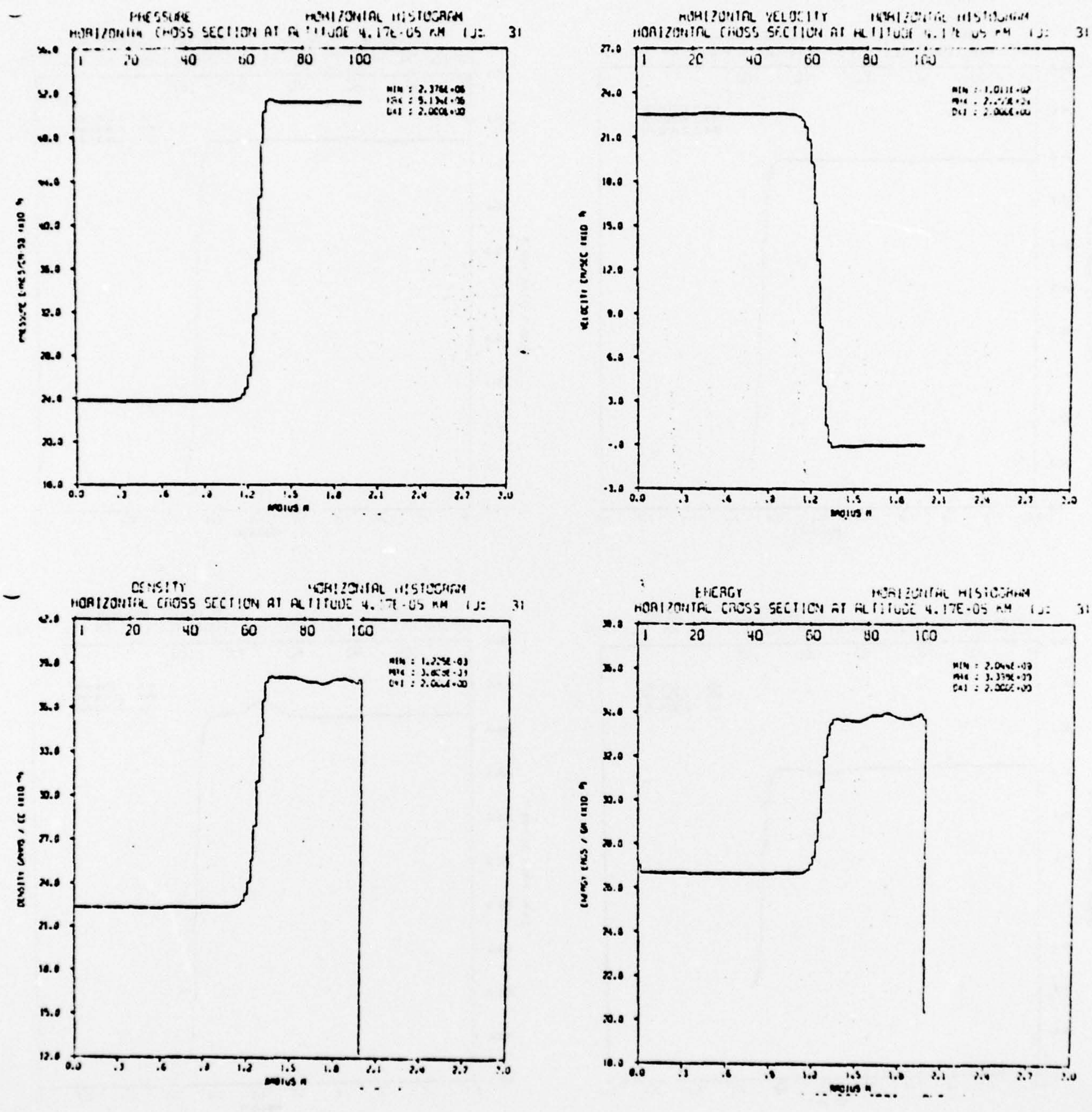

Figure 16. AFWL - 20 psi Square Wave on Wall - Viscosity Function
Time - 4.2 msec, Problem 19.8013.

SECTION IV

TWO HUNDRED PSI CALCULATIONS

DEFAULT WAVEFORM

The first 200 psi problem (19.8014) was run to evaluate the default waveform (stability factor of 0.5, with no artificial viscosity). At 200 psi the default waveform is nearly perfect, having virtually no overshoot and a spread of four or five zones just before hitting the wall at 700 μsec (fig. 17). The reflected wave at 2.5 msec (1200 psi), however, was quite poorly formed, with an overshoot of about 25% (fig. 18).

THE EFFECT OF DEFAULT VISCOSITY

The second 200 psi problem (19.8014A) was run with the default viscosity coefficients (C_1 = 0.5 and C_0 = 0). The incident waveform at 700 μsec had no overshoot but was spread over about eight zones, which was acceptable (fig. 19). The reflected wave at 2.5 msec was considerably improved over the default 200 psi problem, having an overshoot of about 1.8% and a spread of six zones (fig. 20).

WITH THE ARTIFICIAL VISCOSITY FUNCTION

Finally, a third 200 psi problem (19,8014B) was run with the AVF implemented. For this problem, C_1 = 0.591 (incident) and 1.106 (reflected). The incident (200 psi) waveform at 700 μsec showed no overshoot, a slightly rounded top leading edge, and an acceptable spread of about eight zones (fig. 21). The reflected waveform (at about 1200 psi) at 2.5 msec showed virtually no overshoot, a slightly rounded bottom leading edge, and a spread of about 10 zones (fig. 22).

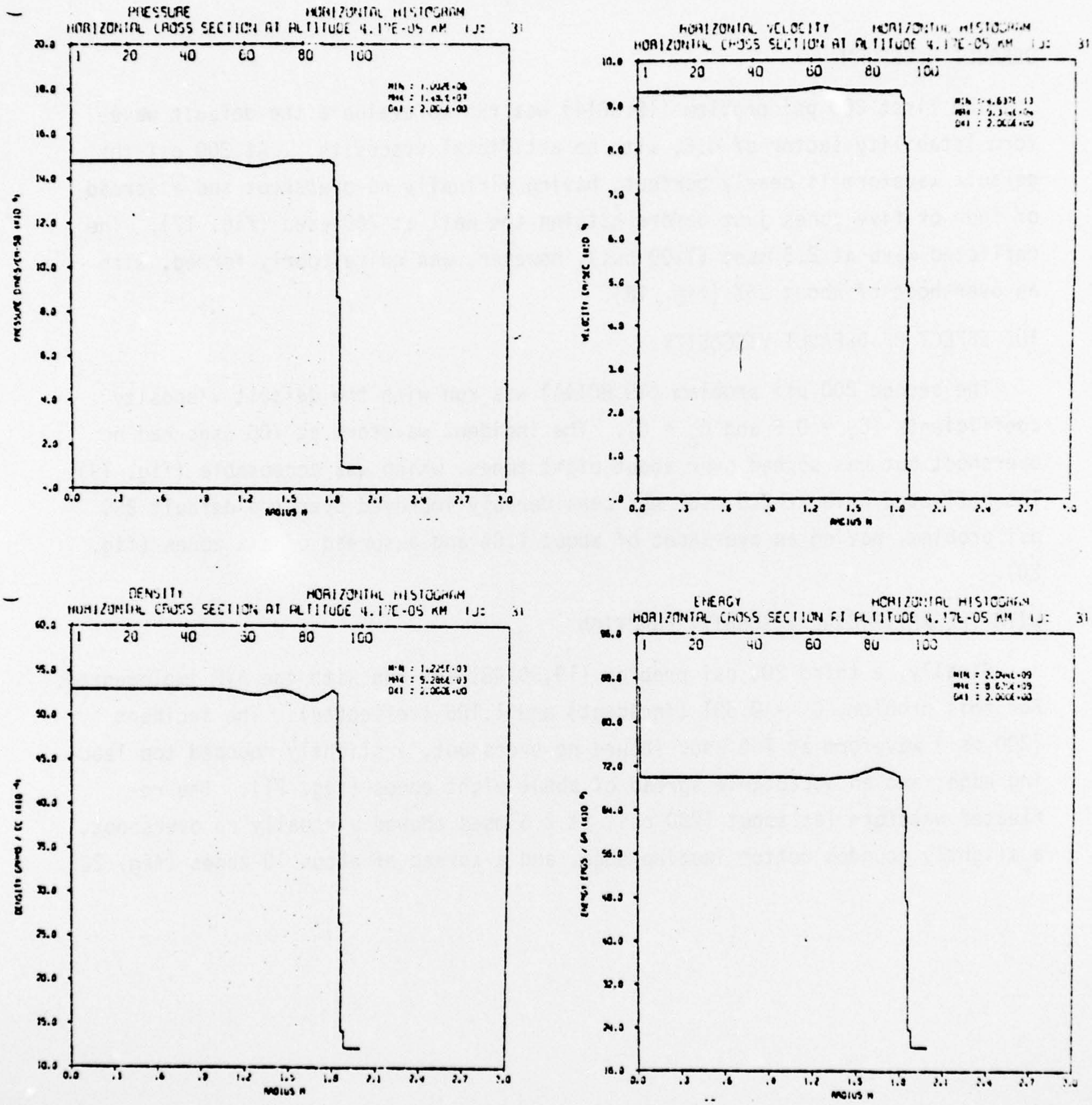

Figure 17. AFWL - 200 psi Square Wave on Wall - No Viscosity
Time - 700 µsec, Problem 19.8014.

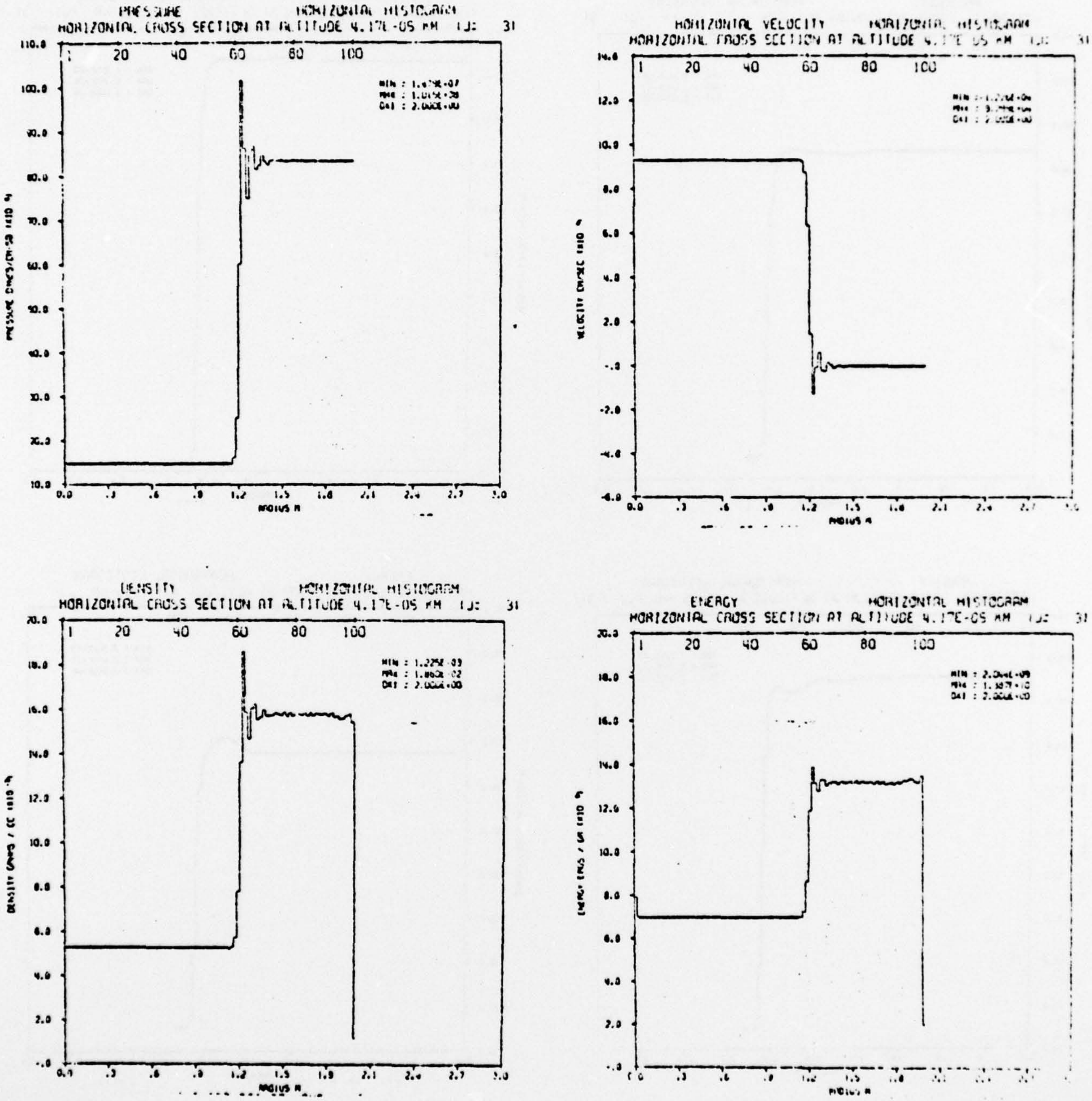

Figure 18. AFWL - 200 psi Square Wave on Wall - No Viscosity
Time - 2.5 msec, Problem 19.8014.

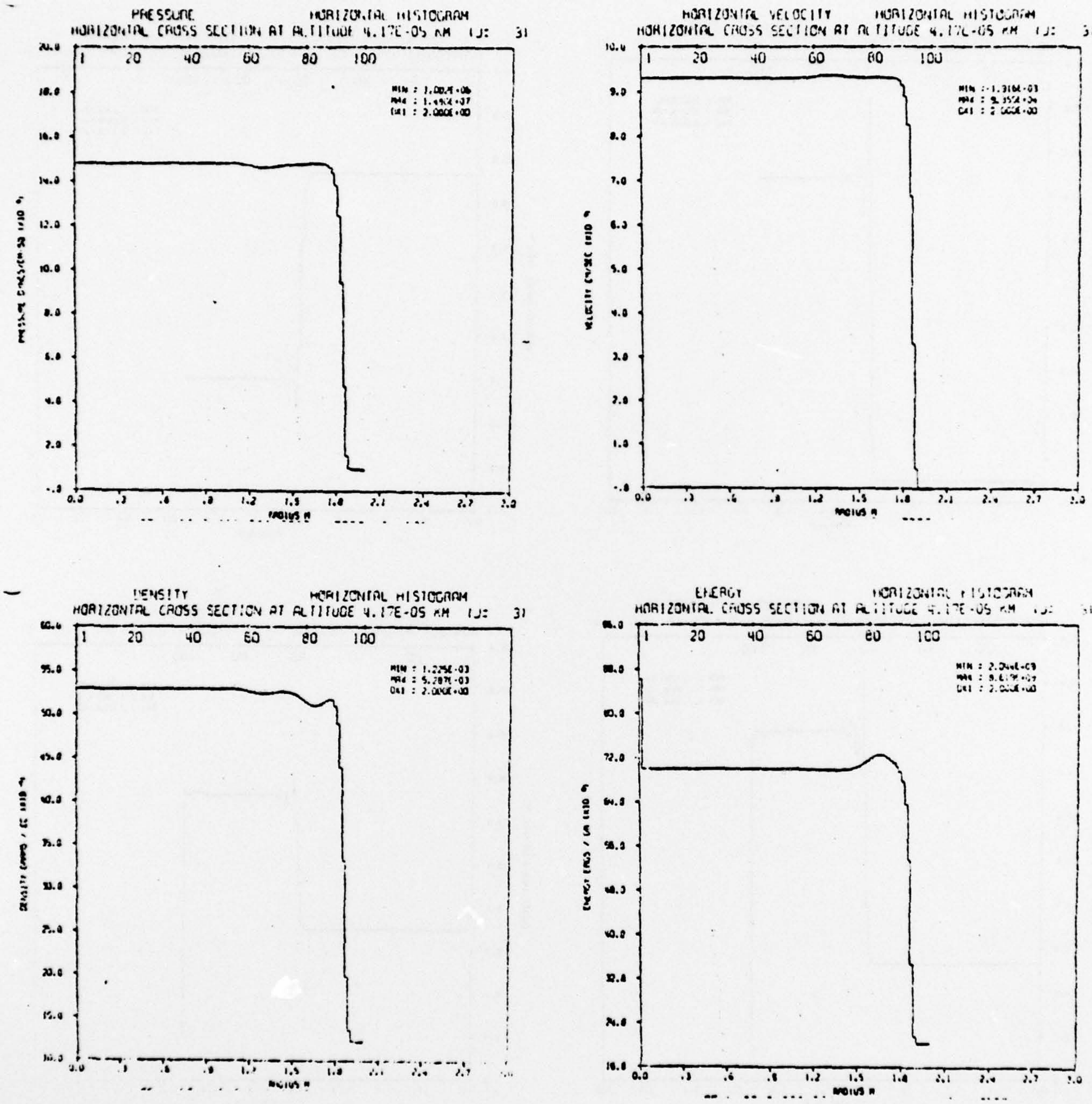

Figure 19. AFWL - 200 psi Square Wave on Wall - Default Viscosity
Time - 700 μsec, Problem 19.8014A.

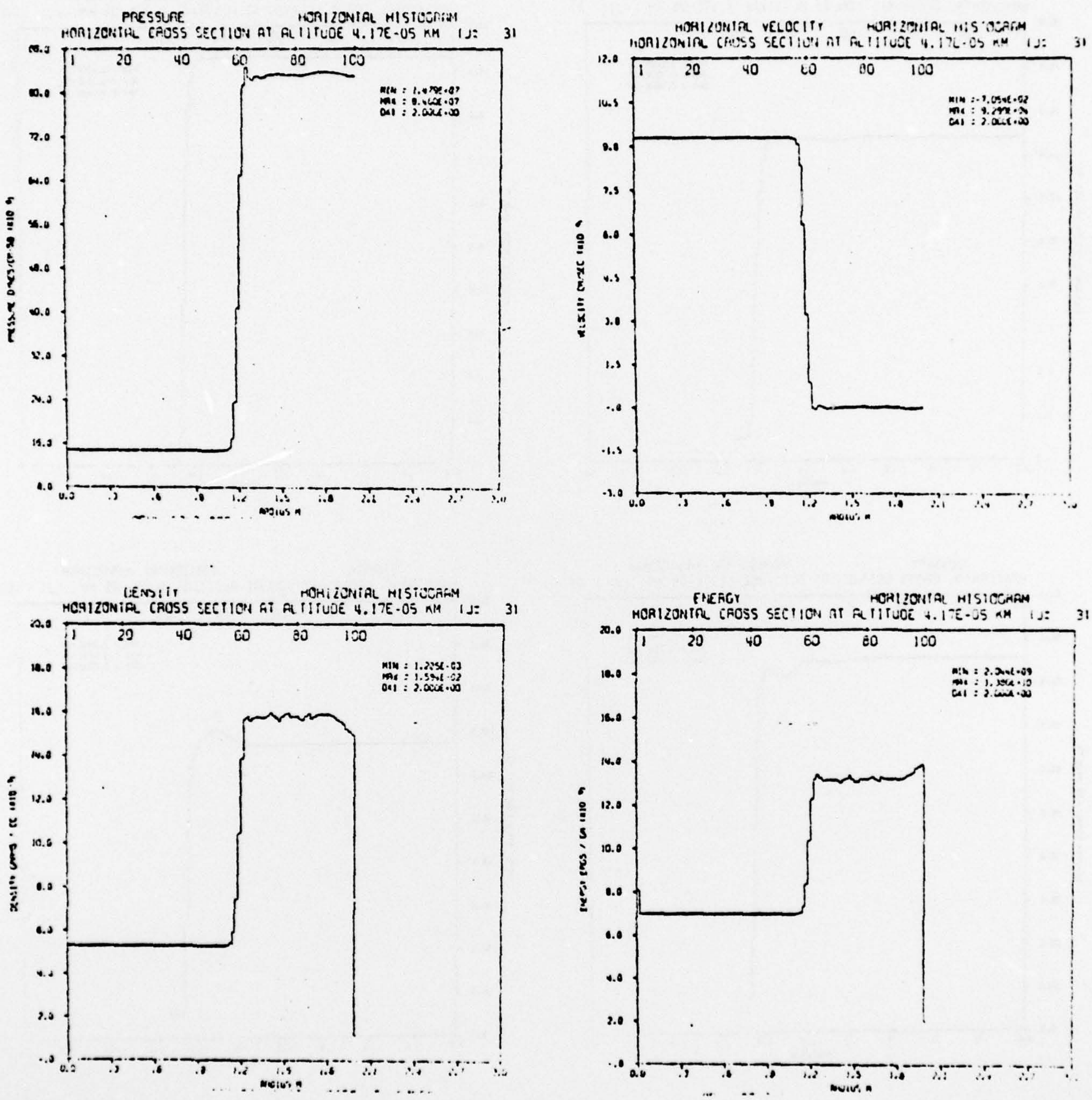

Figure 20. AFWL - 200 psi Square Wave on Wall - Default Viscosity
Time - 2.5 msec, Problem 19.8014A.

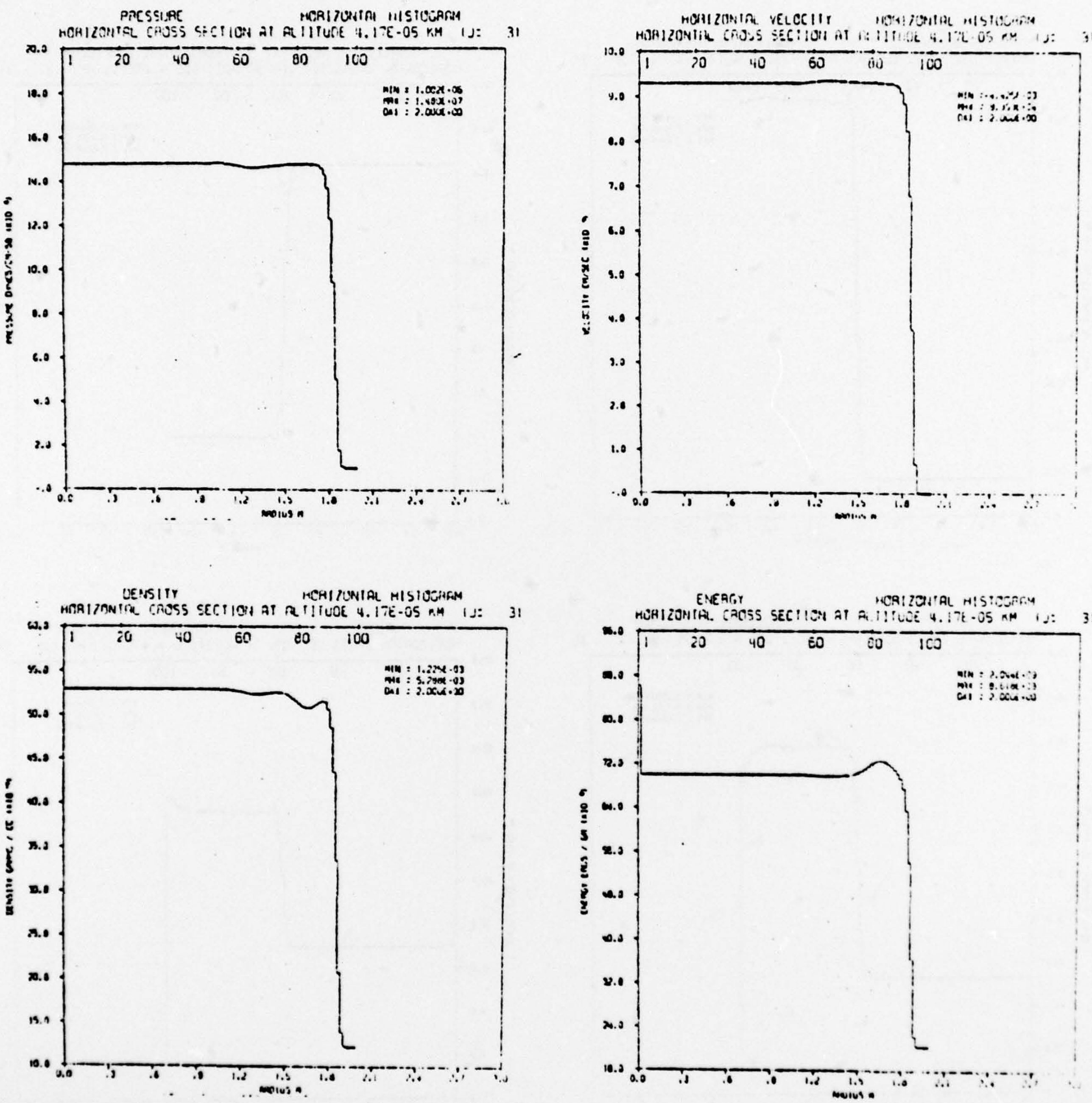

Figure 21. AFWL - 200 psi Square Wave on Wall - Viscosity Function
Time - 700 μsec, Problem 19.8014B.

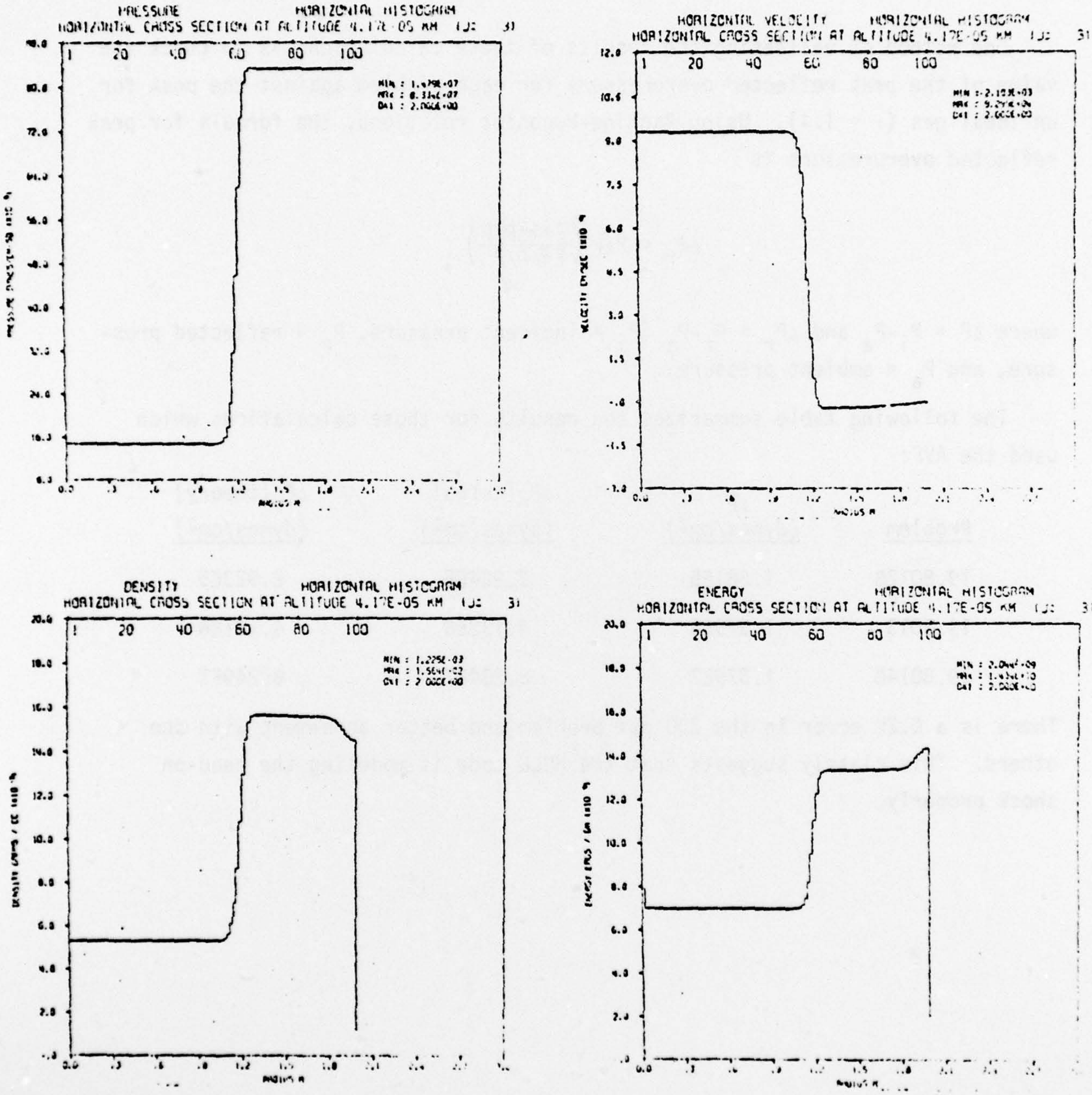

Figure 22. AFWL - 200 psi Square Wave on Wall - Viscosity Function
Time - 2.5 msec, Problem 19.8014B.

SECTION V

REFLECTION FACTORS

One method of validating the results of these calculations is to check the value of the peak reflected overpressure for each problem against the peak for an ideal gas ($\gamma = 1.4$). Using Rankine-Hugoniot relations, the formula for peak reflected overpressure is

$$\Delta P_r = 2\Delta P \left(\frac{7+4\Delta P/P}{7+\Delta P/P}\right)$$

where $\Delta P = P_i - P_a$ and $\Delta P_r = P_r - P_a$ (P_i = incident pressure, P_r = reflected pressure, and P_a = ambient pressure).

The following table summarizes the results for those calculations which used the AVF:

Problem	ΔP (dynes/cm^2)	ΔP_r(actual (dynes/cm^2)	ΔP_r(theory) (dynes/cm^2)
19.8012B	1.381E5	2.924E5	2.923E5
19.8013	1.379E6	4.132E6	4.131E6
19.8014B	1.379E7	8.234E7	8.249E7

There is a 0.2% error in the 200 psi problem and better agreement with the others. This clearly suggests that the HULL code is modeling the head-on shock properly.

SECTION VI

CONCLUSIONS

The HULL code can provide a stable, sharply-defined shock for any overpressure level from 2 psi to 1200 psi using the artificial viscosity function presented in this report. Both the incident and the reflected waveforms are stable yet defined sharply enough so that valid pressure levels for blast environments may be calculated.

REFERENCES

1. Richtmyer, R. D. and Morton, K. W., Difference Methods in Initial Value Problems, Interscience: New York, 1967, pp. 311-317.

2. Fry, M. A., et al., The HULL Hydrodynamics Computer Code, AFWL TR-76-183, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, September 1976.

3. Whitaker, W. A., et al., Theoretical Calculations of the Phenomenology of HE Detonations, AFWL TR-66-141 (Vol 1), Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, November 1966.

4. Needham, C. E., et al., Nuclear Blast Standard (1KT), AFWL TR-73-55 (Rev.), Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, April 1975.